Effects of High Water Table and Waterlogging on Sunflower Growth, Yield and Seed Quality

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Abstract

Understanding the response of sunflower (*Helianthus annuus* L.) to high water table and waterlogging is important for successful cultivation in monsoon Asia. We examined the physiological responses of sunflower cultivars to these conditions. In the rotational paddy field, where the water table depth was shallow, growth of the plant was suppressed, seed yield was decreased and harvest quality was deteriorated. In the artificially inclined field, the ditch surrounding the sloped plot was constantly filled with water, the growth of plant and oil concentration were decreased significantly when the water table was shallower than about 30 cm. In the pot experiment, where water was logged at different growth stages, the relationship between seed yield and the underground dry weight was significant ($r = 0.87$, $p < 0.01$). In cultivars with vigorous growth of underground part, many adventitious roots were appeared. Screening for the appearance of these roots may be an effective way to select sunflower cultivars that are capable of tolerating high water table and tolerating waterlogged conditions and avoiding decreases in seed and oil yield.

Keywords: sunflower, water table, waterlogging, seed quality, adventitious roots

Introduction

Regarding the effects of short-term waterlogging on sunflower, there were some reports about that to the growth, yield and quality. Orchard and Jessop (1984) reported on sunflower and sorghum that growth stages were greater importance than the duration of waterlogging. And Orchard and So (1985) reported that waterlogging at the vegetative and floral initiation stages reduced the root growth and it reduced the water use and nutrient uptake (Orchard *et al*. 1986). Grassini *et al*. (2007) reported waterlogging during grain filling determines direct physiological responses that decrease grain yield. Regarding the fatty acid, there were some reports on the factors changing their compositions. The temperature condition was widely reported as one of the factors. Nagao *et al.* (1984) and Sobrino *et al.* (2003) reported that the oleic/linoleic acid ratio was increased with higher temperature during grain filling. But there are few reports about the effects of shallow water table to sunflower growth and quality.

We are studying the cultivation of sunflower on rotational paddy field for the purpose of human consumption, and for the use of bio-diesel fuel. In the field, the shortening of maturing periods and reductions of stem length, leaf number and disk diameter were observed in many cultivars. And the decrease of seed yield and oil content, oleic acid composition and the increase of linoleic acid composition were also observed. The objective of this paper is to elucidate the effects of shallow water table on the growth, yield and quality and to elucidate the effects of waterlogging in different stages and in different cultivars of sunflower.

Materials and Methods

Field and pot experiments

Experiments I was conducted in 2007 and 2008 on an artificially sloped plot at Ibaraki Agriculture Institute (Ryuugasaki, N: 35°54', E:140°12')The slope had 8.3 m in length and 0.86 m in height at one end. It could set of 10 rows with different water table. Their water table depths were from 0 cm to 86 cm in 2007, and from 3.7 cm to 78 cm in 2008. The row spacing was 0.95 m in 2007 and 0.90 m in 2008 and the distance between plants was 0.2 m in both years. The ditch surrounding the sloped plot was constantly filled with water after establishment of seedling until the finish of the experiment. Soil moisture content was measured by a soil moisture probe (Profile Probe PR2, Daiki Rika Kogyo Co. Ltd., Tokyo). Two hybrid varieties were used. One was traditional type; the name was Hybrid sunflower (Hy.) (Kaneko Seeds Ltd. Gunma), and the other was mid-oleic type, 63M80 (Pioneer Hi-Bred International, Inc., USA). They were sown on 7 June in 2007 and on 5 June in 2008 as early sowing and on 26 June in 2007 and in 2008 as late sowing. Before planting, a chemical fertilizer was applied at the rate of N-P_2O_5-K_2O = 8.4-8.4-8.4 g m^{-2}, in 2007 and 2008. Root growth of the two cultivars at flowering (22 Aug.) was examined by excavating the whole root systems of three plants in late sowing block in 2008 at two water depths (3.7 cm and 20.2 cm). Stem length, leaf nitrogen, number of seeds per a flower disk, flowering date, and maturing date were measured. Soil moisture content was measured by a soil moisture probe (Profile Probe PR2, Daiki Rika Kogyo Co. Ltd., Tokyo). Yield of each plot was determined using the same method as reported by Izquierdo et al. (2002). Thousand kernel weight, oil content and fatty acid composition were measured by the same method as reported by Yasumoto et al. (2011). All treatments were replicated two or three times depending on the varieties.

Experiments II was conducted in 2010. It was examined effects of waterlogging on sunflower at different developmental stages by a pot experiment. The pots were 50 cm long, 65 cm wide and 45 cm deep. Seven hybrid varieties were used. In the cultivars, 3 were traditional type, 4 were mid-oleic type. Before planting, a chemical fertilizer was applied at the same rate as in Experiment I. Waterlogging treatments were imposed at different developmental stages, establishment and flower bud visible. The control was irrigated according to the necessary. Because the flowering time was delayed by waterlogging at the stage of establishment, the seeds of the plants for this treatment were sown on 25 May, while the others were sown on 4 June in 2010. The duration of the waterlogging was the same as in the experiments reported by Wample and Davis (1975), namely 4 days in each treatment. The parameters as in Exp. I were measured. And root dry weight and total dry weight were also measured. Yield and seed quality were measured as in Exp. I. The sampled roots were carefully washed using a colander. The roots and other samples were dried at 60 °C until constant weight (for about 48 hr.) in a forced-air circulation oven, to determine the dry weight.

Sample and data analysis

Sampled seeds were air-dried. Two g seeds from each sample were crushed and the oil was extracted with *n*-butyl alcohol. The measurement of oil concentration and fatty acids composition in total fatty acid were determined by the method of Caviezel (Pendl et al., 1998) using a gas chromatograph (B-820,NihonBüchCo.Ltd.,Tokyo). The concentrations of fatty acids were calculated from their peak areas. And the percentage of the total fatty acid content was calculated from their peak areas.

Statistical analysis

The results were analyzed by ANOVA. All statistical analyses were performed with SPSS 11.0 for Windows (SPSS, 2001). All values are expressed as mean values. Significant differences were established by the Tukey's test at P<0.05. A correlation was calculated and the significance levels (P<0.01) are based on the Pearson coefficients.

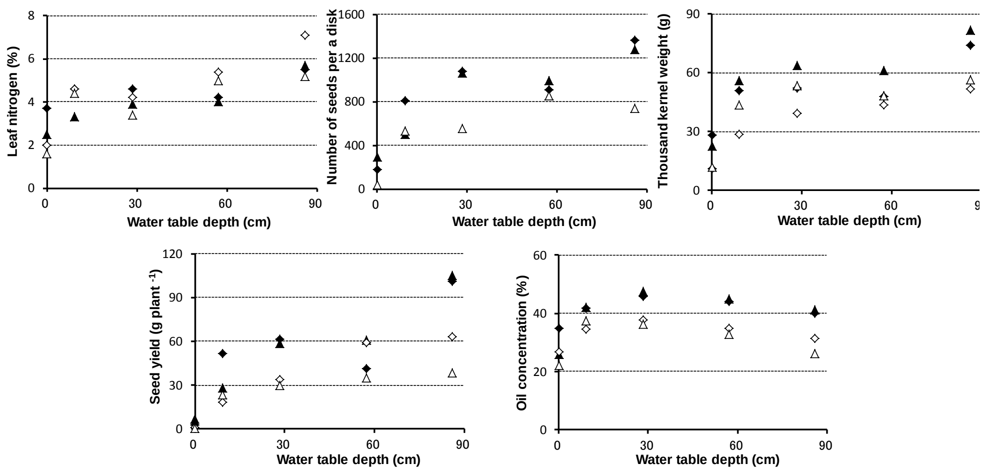
Results

Exp. I. Effects of water table depth on growth, yield and quality

In both years, stem length, disk diameter and seed and oil yield were significantly reduced with shallower water table. Even in the condition that the depth to water table was 3.7 cm, Hy. grew more vigorous roots near the ground surface than 63M80 (Fig. 1a-b). Fig. 2 showed the decrease of leaf nitrogen, number of seeds per a disk, thousand kernel weight, seed yield. That was clearer upper than about 30 cm of the depth to water table. Oil concentration was also decreased upper than about 30 cm of the depth to water table. And oil concentration was some higher in early sowing block. The decrease in oleic acid and the increase in linoleic acid with rising water table were also somewhat clearer in the plants sown on early sowing block. Their results were shown about same tendency in 2007 and in 2008.

a **b**

Figure 1. Root growth of sunflower grown at water table depths of 3.7 cm (left) and 20.2 cm (right). (a) Hy. (b) 63M80.



◆: Hy., ▲: 63M80 in early sowing, ◇:Hy., △: 63M80 in late sowing.

Fig. 2. Growth, Yield and seed quality in the inclined plot in 2007.

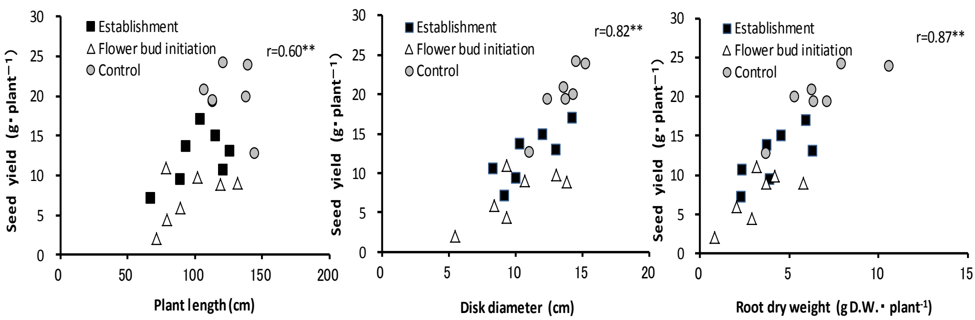
Exp. II Effects of waterlogging on sunflower at different developmental stages

There were significant differences between the stages of waterlogging (Table1). The sunflower was affected by waterlogging (Table1). In many cultivars, seed yield was decreased by waterlogging at the flower bud initiation stage. The response of waterlogging to root dry weight was different between cultivars. In many cultivars, their root weight was decreased by waterlogging at the flower bud initiation stage. In some cultivars, adventitious roots were formed after waterlogging treatment. The high significant relationship between seed yield and plant characters as the disk diameter and the root dry weight were observed through the different stages of water logging treatments (Fig.3).

Table1. Effects of waterlogging treatment on the growth, yield and harvest quality in 2010

Growth stage at waterlogging	Type	Cultivar	Flowering date	Maturing date	Ripening period (days)	Sum. Temp. (℃)	Plant height (cm)	Disk diameter (cm)	Yield (g plant^{-1})	Thousand kernel weight (g)	Oil concentration (%)	Oleic acid (%)	Linoleic acid (%)	Shoot dry weight (g)	Root dry weight (g)
Establishment	Trad.	Hybrid sunflower	July 28	Sep. 2	36	1143	126	13	13.0	24.6	38.7	36.1	50.7	39.5	6.3
		North Queen	July 28	Aug.29	33	984	121	8	10.6	27.2	25.5	42.1	42.9	28.2	2.4
		IS3011	July 28	Aug. 30	34	1009	104	14	17.0	36.7	35.2	40.2	47.7	47.4	6.0
	Nusun	63M80	July 28	Sep. 2	37	1170	67	9	7.1	19.5	12.2	68.5	19.0	13.9	2.3
		Hysun521	July 26	Aug.26	32	935	89	10	9.4	27.6	30.3	58.0	27.9	29.4	3.9
		Hysun 511	July 26	Aug.26	32	945	93	10	13.7	32.9	31.5	67.5	18.9	29.3	3.8
		Hysun530	July 25	Aug.26	33	992	115	12	14.9	26.0	34.6	69.3	17.3	34.7	4.6
Flower bud initiation	Trad.	Hybrid sunflower	July 31	Sep.1	33	1039	102	13	9.8	25.0	33.4	35.1	49.7	41.6	4.2
		North Queen	July 28	Aug.26	30	871	132	11	9.0	24.6	30.8	43.6	42.1	50.6	3.7
		IS3011	July 30	Aug.28	30	864	79	9	4.4	18.1	28.8	37.9	48.3	33.4	2.9
	Nusun	63M80	July 30	Sep.2	35	1124	119	14	8.9	36.6	40.5	72.6	15.1	47.2	5.8
		Hysun521	July 29	Aug.28	31	982	89	8	5.9	21.1	29.3	65.0	21.8	26.0	2.1
		Hysun 511	July 25	Aug.26	33	962	78	9	11.0	19.5	30.5	67.8	18.3	33.0	3.2
		Hysun530	July 30	Aug.25	27	908	72	6	2.1	17.8	29.1	70.5	15.7	8.6	0.8
Control	Trad.	Hybrid sunflower	July 31	Sep.1	34	1080	138	14	19.9	34.2	34.7	38.7	47.1	39.7	5.3
		North Queen	July 30	Aug.26	28	826	144	11	12.7	27.4	29.6	43.6	41.3	57.0	3.7
		IS3011	July 30	Sep.1	34	1048	121	15	24.2	31.6	37.9	35.2	52.9	54.9	7.9
	Nusun	63M80	July 29	Sep.2	36	1141	139	15	23.9	35.8	43.0	72.3	17.6	62.8	10.6
		Hysun521	July 29	Aug.31	34	967	114	14	19.3	28.8	37.1	63.2	24.1	62.1	7.1
		Hysun 511	July 26	Aug.26	32	761	107	14	20.8	24.6	32.6	61.0	25.9	62.7	6.3
		Hysun530	Aug. 1	Aug.31	32	876	113	12	19.4	26.5	30.2	74.2	11.0	61.3	6.4
		Stage			**	**	**	**	**	**	*	ns	ns	**	**
		Cultivar			**	**	**	ns	*	**	**	**	**	ns	ns
		Stage×Cultivar			**	**	**	ns	ns	ns	ns	ns	ns	ns	*

ns, not significant. **, * indicated statistically significant at P<0.01 and 0.05.
ns, not significant. ** indicated statistically significant at P<0.01.



** indicated statistically significant at P<0.01.

Figure 3. Relationship seed yield and plant characters after each water logging treatment.

Discussion

In Exp. I**,** the plant growth and seed yield were reduced with shallower water table while the oil concentration was highest in the plot with a water table depth of 30 cm. It was quite shallow. And from this result, it was thought that the growth, yield, and seed quality of sunflower were affected by soil moisture conditions. In Exp. II, there were differences in the response to waterlogging between cultivars. In some cultivars, adventitious roots were formed after waterlogging. Kramer (1951) reported the adventitious roots contributed to plant survival during flooding. Wample and Davis (1975) reported that adventitious roots formation was one of the responses to flooding. And Jackson (1955) reported that when the original root system was flooded, adventitious root developed to prevent injury to the shoot and to promote shoot recovery from flooding. And in Exp. I**,** the differences of root growth between cultivars was also observed. Even in the condition that the depth to water table was 3.7 cm, Hy. grew more vigorous roots near the ground surface than 63M80. So this difference of appearance of the root was thought to be related to differences in the ability of these cultivars to tolerate flooding and high water table.

These results of this study suggested that the water management was important for improving the growth and quality of sunflower. Further research is needed to identify the physiological mechanisms responsible of sunflower to excess soil moisture.

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-- back to Table of Content --